

CONTACTLESS SYSTEM OF EXCITATION CURRENT MEASUREMENT IN THE WINDINGS WITH HIGH INDUCTANCE

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Abstract – *The results of development, manufacturing and testing of a special contactless maintenance-free excitation current measurement system intended for the windings with high inductance, typical for superconductive alternators, are presented. The system was assembled on the brushless exciter is intended for 1 MVA wind-power generator with the winding, manufactured of high-temperature superconductors (HTSC). The alternator with brushless exciter were manufactured and successfully tested.*

Keywords – *excitation current, superconductivity, contactless measurement, digital signal processing, Hall sensor, quench protection*

I. INTRODUCTION

One of the specific features of alternators with superconducting excitation windings is high inductance of the windings. It refers to all types of alternators: generators, motors, synchronous condensers [1]. There is no major difference in low- or high-temperature superconductors in this aspect. The control of the excitation current value is important because of possible quench of the winding with transition from a superconductive to normal state. It results in appearance of high electric resistance and high voltage on the excitation winding terminals. Not to destroy the winding special protection system is envisioned. It gets the signals from the current and temperature measuring systems.

The current measuring system was developed for 1 MVA wind-power generator with HTSC excitation winding and brushless exciter. The alternator comprises a multi-pole winding. The coils are manufactured of HTSC tape of the 2-nd generation with relatively low current value and as a result high inductance value. The rotor has cryogenic cooling. The armature is of a conventional type. It was decided to make a brushless exciter operating with conventional air-cooling. It contains the main exciter and sub-exciter and is independent of external current supply [2]. Electrical connection of exciter with the excitation winding, i.e. copper wires with HTSC, is performed within the rotating shaft.

The whole complex was manufactured and successfully tested within the SC «Rosatom» Program «Superconductive Industry» [3].

The main aim of the work is the development of contactless maintenance-free system of excitation current measurements. It is to be responsible for the following: possibility of measurements in the current operating range; independence of the accuracy of measurements from the rotor frequency of rotation; insensitivity to external thermal, electromagnetic or mechanical influences; repeatability in case of serial production with application of a maximum possible amount of standard elements.

II. OVERVIEW OF APPLIED MEASUREMENT SYSTEMS

Analysis of existing systems of excitation current measurement in turbogenerators with both independent and brushless excitation systems revealed several drawbacks, making them not applicable for superconductive wind-power alternator [4-10]. They either comprise subjected to wear rotating elements or are influenced by numerous factors misrepresenting the final result. Moreover in many cases they have negative influence on the safety of operation. The latter is very important for the wind-power installations.

Specific feature of the developed superconductive alternator with brushless exciter is as mentioned above electrical connection of copper and HTSC current leads is performed inside the shaft of the device. Therefore even very attractive variants of patents [10] cannot be applied.

Modern measuring systems are mainly based on application of Hall sensors. The latter posses the following advantages: galvanic isolation of the prime and secondary (measuring) circuits, high sensibility, wide temperature range, etc. Measuring systems, based on Hall sensors, provide high reliability, very low total error and allow to decrease the volume of the device [11, 12].

III. MAIN FEATURES OF THE DEVELOPED SYSTEM

The wind power alternator operates with a brushless exciter. The measuring system is one of the elements of the complex.

During the system development process several principal conditions, obligatory for performance, were accepted: rejection of application of units subjected to wear, application of sensors, not possessing their own inductance, excluding or decreasing of units with residual magnetization, easiness of setting, calibration and exploitation.

Calculation and manufacturing of the system started from the rotating coil without magnetic core (Fig. 1).

The coil consists of non-magnetic disc 1, contact bolts 2, two counter wound windings 3. The coil is fixed on the brushless exciter shaft 4 with current leads 5 within it, connecting the exciter with HTSC excitation winding.

The ELCUT calculating program, applied to the design, showed the magnetic induction value equals several mT within a distance of 10 mm from the coil. The value is absolutely adequate for application of modern magnetic field sensors.

To choose the element with proper magnetic sensibility the experience of serial industrial devices application, based

on Hall sensors, magnetoresistances, magnetodiodes and magnetotransistors [13]. The choice was made in favor of the element, based on the design of magnetoelectronic reproducing head. The principal peculiarity of these meters is

based on linearity of Hall sensor electromotive force characteristics up to the frequency of several MHz. The sensor design represents a Hall pick-up 4, positioned in additional air-gap 3 of ferrite circular core 2 (Fig. 2, a).

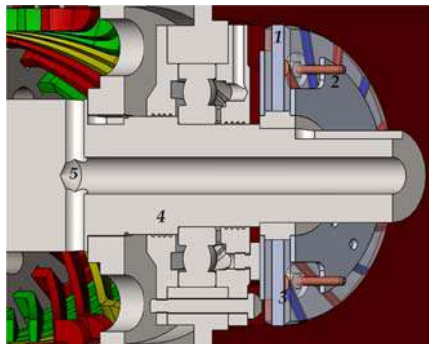


Fig.1. 3D cross-section of the unit, connecting brushless exciter with wind-power alternator HTSC winding

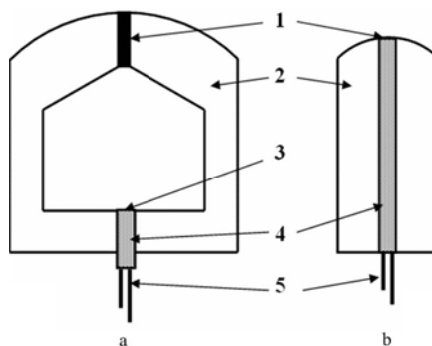


Fig. 2. Principal scheme of magnetoelectronic reproducing head with Hall pick-ups.

The main air-gap 1 faces the source of measured magnetic field.

The industrial magnetoelectronic heads possess high sensibility and a wide frequency range.

Therefore the sensor was manufactured on the base of a serial item, that was initially close to necessary frequency and magnetic field values (45-135 Hz at 300-900 rpm, 9-turn coil and magnetic field value 1.4 mT on a distance 5 mm from the sensor to the coil).

The chosen device was CSLA1CH (firm "Honeywell"), possessing the following parameters: peak voltage – 150 A, sensibility – m 19.6 mV/turn, feeding voltage equals 12 V.

The device [14] was subjected to revision with respect to the processing of the device frame and addition of operating magnetic gap, equal to 4 mm (Fig. 3)

To obtain the characteristics of the improved device several tests with determination of the sensor sensibility and possibility of screening from undesirable magnetic fields influence (Fig. 4) were carried out. In the first test the distance between the pick-up and the coil was 2 mm with feeding voltage 12 V. In the second test the influence of external magnetic field on the data of non-screened and magnetically screened device was measured.

The screen represents a steel tube with oval cross-section.

IV. MANUFACTURING AND TESTING



Fig. 3. Sensor CSLA1CH prior to and after modification.

Experimental results allowed to conclude the sensor is workable at external magnetic fields on the screen surface up to 0.1 T.

As far as during the alternator operation it is necessary for the signal from the sensor to be close to sinusoidal one with the frequency, equal to the frequency of the alternator and the exciter rotation, a special high-speed microcontroller is applied for data processing. The coordination of the sensor output voltage level with the microcontroller input was performed.

It demanded to calculate and manufacture a low frequency first order filter based on operational amplifier of LM258N type with the cutoff frequency 10 kHz and coefficient of amplification equal to 16.

The process of assembly of the unit with microcontroller is presented in Fig. 5.

The microcontroller type is «pic16f628a», the data processing is performed by specially developed algorithm.

The algorithm excludes misrepresentation of measuring system readings because of sensor signal deviation with respect to zero. The microcontroller measures amplitudes of two adjacent signal surges and integrates the average value during one turn – it corresponds to 18 measurements. The presence of low frequency filter excludes high frequency disturbances in the scheme of level coherence.

Temperature drift and external magnetic fields have much lower frequency as compared to the frequency of measurements and are ignored by the microcontroller. As a result high accuracy of measurements is obtained.

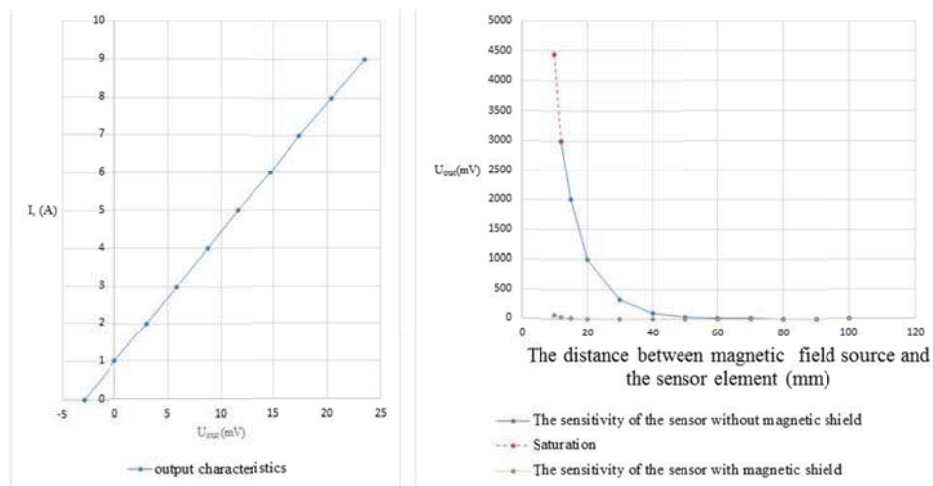


Fig. 4. Sensor CSLA1CH experimental data: a)– graph of the sensor during tests, b) – curves, characterizing sensibility to external magnetic field.

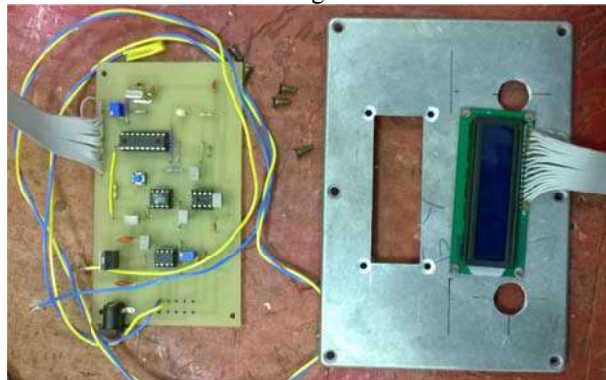


Fig.5. Assembly of the microcontroller unit.

The results allowed to conclude that the sensor is efficient under the operating conditions of the alternator and brushless exciter. The device sensibility equaled 3 mV/A.

The scheme of final design is presented in Fig. 6, a: 1- magnetic screen, 2 – sensor within the screen. The screen with the sensor is fixed to the exciter frame 3 above the rotating coil 4.

.Electronic part with the sensor in magnetic screen was impregnated with epoxy. The final view of the contactless

current measuring system, fixed on the frame of the brushless exciter is presented in Fig. 6, b.

After the system assembly the comprehensive testing was carried out current 60 A and maximum current 100 A. The experiments were carried out on a special test-bed targeted for the full scale investigations of the brushless exciter and contactless measuring system,

The results, referring to the measuring system, are shown in Fig. 7. The data was obtained by a four channel digital oscilloscope.

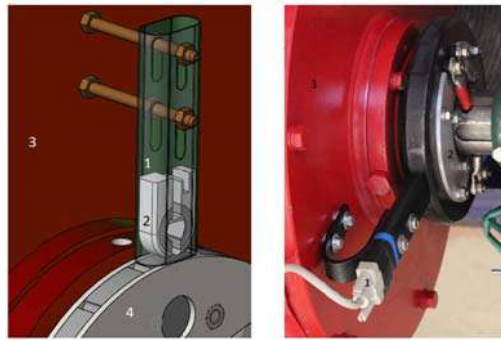


Fig. 6. Measuring unit, assembled on brushless exciter: a) – schematic view, b) – view of the manufactured device.



Fig. 7. Oscillograms, obtained during the contactless measuring system tests.

The pink curve represents the signal from the sensor. The curve has specific “steps” caused by relatively big coil winding step. A small deviation of about 250 mV may be witnessed as well due to the influence of the main bars, rotating with the exciter shaft (on the test-bed the exciter was tested individually, without the main alternator).

To present the signal form relative to the position of the shaft the first channel of the oscilloscope was switched to the phase of the sub-exciter AC winding, positioned on the main shaft (yellow curve). Four periods of the sinusoid correspond to one turn of the system.

The signal from the sensor corresponds to the calculated value and after its processing the true excitation current value may be obtained and in case of kIc excess (Ic – critical current of superconductor, k – safety factor) special measures of superconductive excitation winding protection from transition to normal (non-superconducting) state enter into force.

V. CONCLUSIONS

The results show a principal possibility to increase substantially the accuracy of contactless systems of electric current measurements. Moreover the systems may be maintenance free without periodical technical servicing. They may be applied for a variety of devices both conventional and superconductive ones.

REFERENCES

- [1] Danilevich Ja.B., Chubraeva L.I. New generator designs and problems of their development / Saint-Petersburg, Nauka, 1994. 224 p.

- [2] Devyatova T.A. Project «Innovative energetics. Superconductive industry» / Nuclear Strategy XXI, № 128, July 2017. P.8-10.
- [3] Chubraeva L.I., Timofeev S.S. Brushless exciter based on nanomaterials for 1 MVA HTSC wind power alternator / Materials Science Forum, Vol. 856, 2016. P.38-43.
- [4] Contactless excitation current measurement of brushless generator / Pat. DE 19712108671. Publ. 15.05.1975.
- [5] Polyakov V.I. Measurement of rotor current in generators with brushless excitation // Electrical stations. Electrical Stations, № 2, 2001. P. 59-61.
- [6] Tsvetkov B.A. et al. Cop. Sert. 1436649 (USSR) Method of determination of short-circuits in rotor winding of synchronous electrical machine / Publ. 1988, №41.
- [7] Polyakov V.I. Pat. № 2011203 (RF). Method of rotor current measurement in a generator with brushless exciter / Publ. 15.04.1994.
- [8] http://works.doklad.ru/view/lw_ThEKBo_Y/3.html
- [9] <http://diagnostica-em.narod.ru/shetki.pdf>
- [10] Popov I.N. et al. Method of measuring of rotor current in synchronous generator with brushless excitation / Pat. № 2327273 (RF). Publ. 20.06.2008.
- [11] Bolotin O.A. et al. Modern sensors for current and voltage measurement / Moscow, ISUP, № 1(61), 2016. 5 p.
- [12] Gilardy M. New horizons for sensors based on Hall effect / Power electronics № 3, 2013. P. 12-15.
- [13] Semjenov A.L. Magnetic materials for micro- and nanoelectronics / Irkutsk, ISU, 2012. 147 p.
- [14] Chubraeva L.I. et al.(RU) Way and generator rotor current measuring device with the brushless excitation / Pat. № 2623696 C1.,pub. 28.06.2017. Bull. #19.